Why the US Should Not Reprocess Spent Nuclear Fuel

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The Nuclear Waste Policy Act of 1982 has stated that spent nuclear fuel is to be disposed of directly on dry land, although the act allows for the exploration of alternatives to direct disposal, including reprocessing. This policy was the result of a determination that the risks associated with reprocessing and recycle of plutonium outweigh any waste disposal benefit or fuel cost advantage. However, because the timetable for disposal of spent fuel that was established by the Act will not be met, there are renewed calls for reprocessing of the fuel. The potential advantages for the reprocessing of spent nuclear fuel over direct disposal are usually stated as lowering future fuel costs and making disposal of nuclear wastes easier. Analyses of fuel cycle costs have consistently shown no economic advantage for the US to recycle plutonium from spent fuel and there is little reason to expect this to change in the next several decades. The alleged waste disposal advantages have similarly been found to be dubious despite technical advances. In fact, reprocessing potentially increases short-term health risks associated with management of nuclear wastes and has not been determined to significantly reduce long-term environmental or health risks after disposal. Although the original schedule for disposal cannot be met, there is still no reason to consider reprocessing a viable option.

I. Introduction

Nuclear power was originally to have a closed fuel cycle. Uranium would be mined and milled, enriched in its fissionable isotope ^{235}U from the 0.7% found in nature, manufactured into fuel and burned in reactors to generate electricity. As it burned, some of the ^{238}U would be converted to plutonium. Then the spent fuel would be removed and transported to a central plant where it would be dissolved and reprocessed chemically. The unburned uranium and plutonium would be separated and would be recycled in new fuel. Plutonium would be saved to use as fuel for breeder reactors, which could burn it efficiently and also make more new plutonium fuel. Recycling of plutonium/uranium fuel in conventional reactors therefore was regarded as logical and essential to the future.[1]

Because the recycle process was assumed to involve the separation of plutonium, and this material, even from the commercial fuel cycle, could be made into weapons, proliferation had always been a concern. The conventional wisdom was that plutonium separated from commercial reactor fuel or the breeder could not be used to make nuclear weapons. But weapons designers recognized that it was physically possible for almost any mix of plutonium isotopes to be used effectively either in a several-kiloton weapon of sophisticated design or in a crude, low-yield weapon that would still be quite deadly.[2] The U. S. had actually exploded a device made of "reactor-grade plutonium" at the Nevada Test site in 1962, but this fact was classified as secret.

On May 17, 1974, India, a non-party to the Non-Proliferation Treaty, detonated a nuclear explosive device.[3] The device (claimed by the Indian Government to be “peaceful”) was constructed using plutonium recovered from fuel irradiated in an Indian electric-power producing reactor. The Indian explosion caused a reappraisal in the US its nuclear energy policies. Congress began work on bills that would tighten the conditions for U. S. nuclear exports. President Ford ordered a hold on the startup of the new reprocessing plants until issues involving safeguards and nonproliferation could be resolved.

In 1975 The Nuclear Energy Policy Study Group, which was initiated by McGeorge Bundy, President of the Ford Foundation (and former National Security Advisor to President Kennedy), undertook a broad examination of the role of nuclear power in the overall energy picture. The Study Group was made up of experts in related fields who had not taken sides in the bitter debate over the role of nuclear power. The group's findings were set forth in "Nuclear Power Issues and Choices," (the Ford/Mitre report) which was released at the beginning of 1977.[4] President Carter used the results of this study in forming his decisions regarding the reprocessing of spent fuel nationwide. The panelist for the study had the following to say about the relationship between US nuclear power and proliferation:

“We believe the consequences of the proliferation of nuclear weapons are so serious compared to the limited economic benefits of nuclear energy that we would be prepared to recommend stopping nuclear power in the United States if we thought this would prevent further proliferation. However, there are direct routes to nuclear weapons in the absence of nuclear power, and the future of nuclear power is not under the unilateral control of the United States. . . In fact, abandonment of nuclear power by the United States could increase the likelihood of proliferation since the United States would lose influence over the nature of nuclear power development abroad.”

The overall economic conclusion of the studies with respect to reprocessing and recycling of spent fuel can be summarized in the following:

“Recycling of uranium in LWR’s would probably be desirable from an economic perspective if reprocessing of spent fuel were judged to be desirable as a precursor to waste disposal or to obtaining plutonium for use in breeder reactors. It is, however, not needed for the first purpose and is premature for the second, in our view.”

After President Carter received the study, he issued an order suspending indefinitely commercial spent nuclear fuel reprocessing in the US. Direct disposal of spent nuclear fuel in geological repositories became the US national policy when codified in the 1982 Nuclear Waste Policy Act.[5] Although there have been amendments to the act, the original date of January 31, 1998 for acceptance of spent fuel by the US Department of Energy for disposal has never been changed. Because of very difficult political problems at all prospective nuclear waste repositories or storage sites since 1982, and significant technical and political problems at the Yucca Mountain site in Nevada since 1987, the DOE will not be able to accept spent fuel for disposal according to the schedule.

The failure of the federal government to open a National Repository or a Monitored Retrievable Storage Facility over the last 15 years is taken by some to mean that reprocessing of spent fuel should once again be considered an option.[6] However, although the world political situation has changed somewhat, proliferation is still a significant issue and reprocessing of spent fuel by the US will not help the situation. This paper shows that careful analysis will lead one to the conclusion that reprocessing the spent fuel would not help in nuclear waste disposal and would not improve the economics of nuclear power. Indeed the major conclusions of the old Ford Foundation study are either as correct or more correct than before. Moreover, these facts cannot be expected to change at any time in the next several decades.

II. The Last 20 Years

President Carter's decision in April 1977 marked a distinct break from the conventional wisdom inherited from the early days of the nuclear age that reprocessing of plutonium leading to plutonium fuel cycle was the indispensable key to achieving a plentiful supply of cheap nuclear power to meet the accelerating global demand for electricity. Despite the demonstrated ability of nuclear reactors to produce energy, the supply of natural uranium to provide fuel for reactors was originally perceived to be in very short supply which underscored the fact that with less than one percent of this natural uranium was in the form of the isotope ^{235}U that sustained the energy-producing chain reaction in the reactor. A solution to this highly inefficient utilization of an apparently very limited resource was provided by the convenient fact that the plutonium produced in a reactor by the capture of neutrons by the other natural uranium isotope U-238, which makes up more than 99 percent of natural uranium, is also a suitable fuel for reactors. Chemical separation of this plutonium (by them same process used to obtain plutonium for weapons) makes available more fissile material for use in reactors. Moreover, the physics is such that these reactors can be designed to produce more fissile material than they consume. These "breeders" can therefore in principle eventually consume all of the U-238 in natural uranium and thereby increase production of energy from a given amount of uranium by a factor of as much as 100. It was widely assumed that the solution of this problem would simply be a relatively straightforward engineering exercise that would lead to early introduction of plutonium reprocessing and breeder reactors that would solve the world's energy problems.

Unfortunately, plutonium reprocessing and the resulting "plutonium economy" was seen to present a serious new security problem by substantially increasing the danger of proliferation of nuclear weapons. The technology of reprocessing plutonium for civil reactors is the same as that for producing plutonium for weapons. Moreover, with the passage of time it became increasingly clear that even plutonium from civil reactors, operating in a normal fashion, could be used to make nuclear weapons. The not very reassuring response to these serious concerns was that the plutonium from civil reactors would not be as good for weapons purposes as specially produced plutonium and that International Atomic Energy Agency (IAEA) safeguards would give adequate warning of any diversion of materials. Looking down the road, when breeders enter the picture, each reactor might have an inventory of several tons of plutonium, the equivalent of 1000 nuclear weapons. Even with the most effective safeguards, a world in which tons of weapons useable plutonium are being separated and shipped from place to place every year would create far greater opportunities for nuclear theft and diversion.

The Ford/MITRE Group concluded that despite its many serious problems, nuclear energy would and should be a major source of electric power in the future. The study, however, was particularly critical of the estimates of the future availability and cost of uranium, which is central to any decisions on the economic viability of plutonium reprocessing and the need for and timing of breeder reactors. Until the cost of uranium ore rises significantly, it is cheaper to produce low enriched uranium from new ore than to separate plutonium from previously irradiated fuel elements. The study concluded that, if uranium followed the example of other minerals, the higher costs accompanying increased demand would generate much larger supplies than previously forecast as it was discovered that lower grade sources could be profitably exploited.

On the basis of more realistic estimates of uranium reserves and the capital costs involved in plutonium reprocessing, the study concluded that "there is no compelling reason at this time to introduce plutonium or to anticipate its introduction in this century." Since the dangers associated with the plutonium economy, in particular proliferation of nuclear weapons, were seen as far outweighing any possible economic benefit under the most optimistic assumptions for reprocessing the study recommended that a clear cut decision be made "to defer indefinitely commercial reprocessing of plutonium." Such a positive decision to defer was seen as having a major influence on the decisions of other countries to pursue reprocessing while a decision to go ahead would accelerate international interest in the plutonium fuel cycle. Consequently, the study recommended that the government not allow operation of the Barnwell plutonium reprocessing facility which undertaken as a commercial venture and had been ordered mothballed by President Ford.

After Carter issued his statement in April 1977 deferring indefinitely commercial reprocessing of plutonium, he initiated the International Nuclear Fuel Cycle Evaluation (INFCE) Conference which sought to persuade the international nuclear community that economics did not support reprocessing and the plutonium fuel cycle. The United States moved too quickly on the issue and was largely isolated at the conference by the other major players in nuclear power, including: France, Germany, Japan, and the United Kingdom, all of which vehemently rejected the abandonment of the plutonium fuel cycle option. All of these countries along with the Former Soviet Union continue to pursue program involving spent fuel reprocessing.

Although the reprocessing policy was reversed under President Reagan, commercial reprocessing was never re-started in the United States because the federal government had become an unreliable business partner in reprocessing and the profitability of the venture was in serious doubt. The US nuclear industry then as now is not interested in private financing of plutonium reprocessing. In 1983, the Barnwell reprocessing project was finally terminated.

The anticipated demand for uranium did not materialize and new uranium ores of higher quality were discovered. In two decades there have been no shortages of uranium and no increase in cost. In fact, there is such an over-supply of uranium that the cost today (about $12 per pound) is only fifty per cent greater than it was 25 years ago before the energy crisis of the early seventies. Thus, considering the 200 per cent inflation rate that has accrued during this period, the real cost of uranium today is less than half the price at that time and less than one tenth the cost at the time of the Ford/MITRE study. It is difficult to identify any other basic material whose real cost has declined so precipitously. At present many uranium mines have closed because they cannot compete at current prices and there is a worldwide excess capacity of enrichment facilities to produce low enriched uranium for standard light water reactors. In short, there is market for plutonium fuel.

With the end of the Cold War the proliferation risks associated with the potential leakage of plutonium and highly-enriched uranium from the Russian program are now of the highest importance. Attempts by our government to discourage Russia’s reprocessing of their fuel have met with little success. Rather, the US is providing assistance in the creation of secure storage facilities for their excess plutonium. Increased presence of IAEA inspectors in the FSU and US-initiated safeguards measures are helping to decrease risk throughout the plutonium and uranium fuel cycles. However, there remains much work to be done. While the introduction of spent fuel reprocessing in the US at this time would not make matters any worse with respect to proliferation originating in the FSU, it also would not help with the critical safeguarding task.

The Russian nuclear program continues to be driven by the remnants of its centrally-planned economy, where sunken costs are not easily written-off. They view their plutonium and related infrastructure as extremely valuable, a resource not to be wasted. The majority of leaders and citizens still feel that an expanding nuclear energy program is necessary. There is no inertia to cease reprocessing of spent fuel even though there is a dramatic oversupply of nuclear fuels and not enough money to pay for continued operation of many of the existing nuclear power stations.

They also strongly are in favor of using plutonium from dismantled nuclear weapons as fuel for their power reactors. Mainly because of our need to act in unity in disarmament, the US is planning for the option of burning weapon plutonium in reactors. The use of excess plutonium from eliminated nuclear weapons in MOX fuel in commercial nuclear reactors is simply a method of disposing of existing separated plutonium by using it as a reactor fuel. After irradiation it will be no more accessible to theft or diversion than plutonium from normal spent fuel from commercial reactors. To understand that this plutonium is no longer considered a proliferation threat once it has been burned in a reactor is of great importance. It joins the thousands of tons in the nation's spent fuel inventory.

A number of countries, including France,[7] Japan[8] and Russia[9] have continued to pursue plutonium reprocessing and recycle. These countries have invested in nuclear energy programs that include reprocessing and in some cases breeder reactors that they feel will give them lasting energy independence. This seemingly uneconomic solution to their energy problems reflects their desire to maintain independence from Middle East oil supplies and the potential vulnerability to trade disruption. In France, nuclear energy represents a majority of electrical power production and recycle of plutonium in power reactors is common. Japan is even more fuel-poor and is driven by a deep rooted desire for energy self sufficiency going back to its experience during the World War II blockade.

III. Plutonium Loss

The main barrier to proliferation, other than institutional safeguards and Materials Accounting and Control (MC&A) procedures is the chemical and physical form of the plutonium, which is in a hard ceramic intimately mixed with uranium oxide. The uranium content is such that it must be separated from the plutonium before the plutonium is useful for a weapon. The MOX fuel is extremely radioactive after discharge from a reactor so that all separation processes must be carried out remotely behind thick shields or with robotics. The separation and purification process is expensive and complex and in no way should be discounted. It is for this reason that commercial spent nuclear fuel is not normally considered a great proliferation risk. Only separated plutonium metal, plutonium oxide or (to a lesser extent) fresh MOX fuel is usually considered a diversion risk.

MOX fuel is made by mixing plutonium oxide powder with uranium oxide, and fabricating the MOX mixture into small pellets that are loaded into metal rods and formed into fuel assemblies for nuclear plants. This process involves bulk handling of plutonium. Making accurate measurements of bulk amounts of weapon material in MOX fuel fabrication plants has proven difficult. In May 1994 it was disclosed that a major plutonium inventory discrepancy had been building up at Japan's pilot MOX fabrication plant since a new automated line began operating in 1988. The Japanese government had asserted that this plutonium, amounting to about 70 kilograms, or more than enough for eight nuclear warheads, was not missing because it had been measured as "hold-up" material---that is, as plutonium that stuck to surfaces and got held up in the plant's process equipment. But such measurements were taken indirectly by assaying devices, and were subject to significant uncertainty, perhaps as large as 30 percent in some instances.

To deal with the uncertainty, the International Atomic Energy Agency (IAEA) asked Japan to cut open the glove boxes and physically produce and measure the holdup plutonium so that inspectors could verify the plant's inventory. At a reported cost of more than $100 million, and after more than two years of clean-out operations, about 10 kilograms of plutonium (more than a bomb's worth) is still not accounted for. [10,11] Japan thus still fails to meet the safeguards criteria of the IAEA. Plutonium scrap is also a significant source of measurement uncertainty at the MOX fabrication plant, which has generated about 100 to 150 kilograms of such scrap.

The evidence today is that there is a slow but growing increase in the rate of diversions of proliferation-significant materials from the former Soviet Union.[12] There have been several confirmed cases of illegal export of nuclear material, including the discovery of 560 grams of mixed oxides of uranium and plutonium on a Lufthansa Airlines flight from Moscow to Munich. It is thought that the powder was meant for an experimental MOX-fueled reactor in Russia, but no final determination has been made of the source. In any case, security seems to be lacking in many of the smaller, research-related facilities and naval fuel facilities in Russia.

Although material shortages were common in the Soviet Union, there was apparantly never any shortage of weapon-usable material. It is estimated that Russia's nuclear material inventory, which is distributed over 50 sites, consists of 1100-1300 tons of HEU and 165 tons of weapons-grade plutonium. There are significant quantities of nuclear materials in the other post-Soviet states as well. The declared inventory tends to rise with time, as more new caches of material are discovered. For instance, the declared inventory at one research institute in Ukraine grew from 15 to 75 kg during 1996.

International safeguards are designed to deter national governments from divertig nuclear materials from peaceful to military purposes and to detect diversion if it occurs. Since the collapse of the Soviet Union, all the the non-Russian states have signed the Non-Proliferation Treaty (NPT) as non-nuclear weapon states and many have concluded safeguards agreements with the IAEA. Safeguards agreements are currently in effect for Armenia, Latvia, Lithuania and Ukraine. There is little fear of government diversion of nuclear materials in the other states.

Of far greater concern is the prospect that the post-Soviet states will not be able to provide adequate security and safeguards directed at non-state actors. These safeguards emphasize the provisions of physical secirity, material control and accounting (MC&A) and other governmental actions such as intellegence gathering. Physical protection is probably better at Russian uranium enrichment and plutonium production sites than at research institutes and naval fuel facilities . However there are many problems such as the fact that nuclear material scraps and residues did not count in production quotas under the old system. This resulted in large quantities of materials unaccounted for under the Soviet system. There may even be some problems with inadequate security for storage facilities for nuclear weapons.

Progress is being made in providing Western assistance in upgrading MPC&A at key Russian and former Soviet Union facilities, but a tremendous gap remains between the magnitude of the national safeguards problems and the effort that has been directed towards their solution. US assistance to Russia through the various government-to-gevernment programs have contributed significantly to the safeguarding of Russia's nuclear assets. The impact of this assistance can be increased by moving beyond the asymmetric donon/recipient relationship towards a relationship of true cooperation. Foremost this means creating a sense of a shared mission between the former Cold War rivals, without brazen attempt s by the US to alter the Russian commercial fuel cycle.

It is in this spirit that the agreement to convert a fraction of each of the nations' excess weapon plutonium into spent fuel was made. This decision and its impact is discussed in the next section.

IV. Irradiation of Weapon Plutonium as MOX Fuel

For nuclear-weapon states it makes little sense to be concerned with governmental diversion of reactor plutonium into a weapon program for now because of the tremendous quantity of excess of plutonium remaining within military boundaries. Additionally, many thousands of warheads are still in the stockpile. It is sometime argued by arms-control advocates that in a future treaty-breakout scenario, the United States (or Russia) could draw on its historical nuclear test data and predictive capabilities to reconfigure weapons and reconstitute a large arsenal, even from plutonium isotopically degraded to reactor grade by irradiation in MOX. This supposedly constitutes an argument against the irradiation of weapon plutonium as MOX fuel. However if this were true both the US and Russia already have thousands of tons of spent commercial fuel from which they could re-build their arsenals if they so wanted.

Thus, irradiated MOX fuel or spent commercial fuel poses (for practical purposes) an infinite barrier to re-militarization of warhead plutonium in weapon states. The National Academy of Sciences, in its comparison of the MOX and immobilization options, found that "[t]he plutonium in the spent fuel assembly would be of lower isotopic quality for weapons purposes than the still weapons-grade plutonium in the glass log, but since nuclear weapons could be made even with the spent fuel plutonium this difference is not decisive." In future years, if the spent fuel had been “disposed of” in a geological repository, it would make little difference to a determined government, who could certainly dig it up again without difficulty. Thus the term “Spent Fuel Standard” has been coined to signify that there is simply no reason to assure that a given material has greater resistance to proliferation than spent fuel. Any other highly-radioactive material that contains weapon-usable material mixed with low-enriched uranium meets this standard.

Sir Walter Marshall, when he headed Britain’s nuclear power program, called a spent fuel repository a "plutonium mine." However, in either scenario: burning plutonium as MOX fuel or direct disposal, the proliferation risks are low, but neither scenario has an obvious nonproliferation advantage over the other. The long-term risk with direct disposal of spent fuel develops as radioactivity of fission products decays. The dangers to persons from retrieving spent fuel and chemically separating the plutonium can be assessed as a function of time. Decades from now the radioactivity would be low enough to permit mining and reprocessing to separate the plutonium. Also, the plutonium itself becomes less rich in the shorter half-life heavier isotopes, making it a somewhat more attractive weapons material.

If the spent fuel or other material is buried very deeply in a geological repository it may be deemed to meet a second, more stringent standard, the “Materials Production Standard,” (or MPS).[13] That is, if the repository is deep enough and isolated enough, it may be more expensive to mine the repository than to produce new weapon material. Spent fuel in such a facility would meet the MPS, at least initially. If someday the great majority of spent fuel in the world is stored in such a fashion and there is no separated plutonium or fresh MOX fuel available in large quantity, spent commercial fuel stored above ground would then be the relatively fastest route to new weapon production. Until this happens, however, spent fuel is not considered a significant contributor to the overall proliferation threat.

The MOX option for weapon plutonium disposition should not encourage the civil use of plutonium and should not be portrayed as giving credibility to the claim that plutonium recycle in light water reactors is essential to nuclear waste management. Reprocessing proponents should not attempt to exploit the use of MOX in the disposition process as proof of a new US government policy on plutonium recycle.

V. Reprocessing and Recycling Costs and Benefits

A classical cost/benefit analysis will lead one to decide against the recycling option in the present time and for the next fifty years at least. A review of economic analysis published recently by the Electric Power Research Institute (EPRI) shows that the market price of uranium must increase by at least a factor of 5 over its current \$10/lb. price before plutonium becomes competitive with uranium in LWR's.[14] The price requirement may be relaxed somewhat if reprocessed plutonium were to be used to fuel Liquid Metal Reactors (LMR's), in the unlikely event that the LMR's are to be built with lower capital costs than LWR's.

The analysis compares two scenarios. One is the current once-through fuel cycle and the second is with plutonium reprocessing and recycle. In the once-through scenario, uranium ore is mined, converted to uranium hexafluoride and transported to and processed through enrichment facilities. The resulting enriched uranium hexafluoride is transported to uranium-oxide fuel assembly fabrication facilities, converted to uranium oxide and incorporated into uranium oxide fuel assemblies. The fuel assemblies are transported to reactors, used, stored locally, and then transported to their longer-term destinations.

In the plutonium scenario, spent fuel is transported from the reactors that created it and/or from interim storage facilities to spent fuel reprocessing facilities. There the plutonium is separated and is then transported[15] to MOX fuel assembly fabrication facilities, as also is some of the uranium recovered from the spent fuel. MOX fuel assemblies are fabricated and transported to LWR's. These LWR's have been designed to accept MOX fuel as well as uranium oxide fuel, a flexibility that mainly impacts the provisions for new fuel handling and reactivity control. The waste from the spent fuel processing facilities is packaged and, after interim storage, transported to high-level and low-level waste repositories. The bulk of the uranium recovered at the spent fuel processing facilities is stored and then reused as feed to MOX fuel fabrication facilities.

Costs (in the LWR case) include the capital and operating costs of the reprocessing facility (8.5 mills/KWh) and fuel fabrication facility (1.6 mills/KWh). Benefits include the savings from not purchasing uranium yellowcake (2.8 mills/KWh) and not having to enrich it (2.3 mills/KWh). They also claim that reprocessing wastes will be 2 mills/KWh less expensive to dispose of in a geological repository than spent fuel becuase of reduced repository heat loads. The validity of this claim is discussed in the next section.

In the analysis the 2.8 mills/KWh saved by not purchasing yellowcake is a linear function of the market price of uranium. The market price of \$55 per pound U_3O_8 gives this result. Included in the analysis is the cost of starting-up the reprocessing facility, so that the \$55 value is slightly higher than the break-even price. The cost of money to utilities is taken as 5%/year above inflation.

Based on the analysis it is concluded that the time for economically introducing reprocessing and recycle may (with about 50% likelihood) occur within 50 years. They do not recommend slowing the US spent fuel geological isolation program as a result of these findings because adequate spent fuel will be available above ground in the future regardless of whether Yucca Mountain has been opened.

It may be reasonable to accept their findings and advocate delaying reprocessing on the basis of their analysis alone. However, they seem to have ignored the significant effect that increased uranium prices would have on uranium exploration. Because a factor of 5.5 in the price of uranium is a very significant increase, it stands to good reason that a significant amount of new exploration for uranium ores will be undertaken worldwide before the full factor of 5.5 is realized. Yet their analysis is based on currently-known and estimated reserves only.

Reserve and resource estimates for minerals have a long record of being understatements. Estimates of reserves typically originate with industry and reflect its view of what is marketable as well as of what it is prudent to characterize as reserves. These estimates are conditioned by the technology of exploration and recovery and by the extent of exploration. Behind it all this is some concept of the mineral's future significance and the future economic picture. Generally, as markets expand or as prices rise, an industry is motivated to look for, and tends to find, new reserves. This explains why reserve and resource estimates rise along with rising production. One should, therefore, keep an open mind regarding the potential for incremental discoveries and large surprises.

Additionally, the costs associated with mining uranium are taken to be fixed and no allocation is made for improved mining technology in the years ahead. This is to be compared to the analysis they used for reprocessing technology, which predicted that the costs would decrease with time.

The supply of uranium from sea water is known to be extremely large potentially but only at a very high cost of $800/kg U. Again, neglected in the analysis is what would happen to this per-kg cost in the next 50 years due to technology advances, especially under conditions where the market price of uranium is dramatically increasing. If the cost of obtaining the uranium from sea water were to drop significantly, this would exert downward price pressure on uranium.

Based on the above reasoning the 50 year time estimate for the introduction of reprocessing is most likely premature. The conclusion is that the cost of even an infinite delay in the introduction of reprocessing may be zero. Thus the recommendation to defer reprocessing is easy on economic grounds because there is no penalty.

VI. Environmental Benefits to Reprocessing?

A more important consideration is whether reprocessing and recycle can improve the long term health consequences of nuclear waste disposal. The first step is to analyze and identify the species which contribute most to long-term individual doses from geological disposal. For this purpose it is sufficient to focus on the relative values of maximum annual dose to individuals from each radionuclide released from a geological repository.

An advantageous feature of the direct disposal of spent reactor fuel in a repository without reprocessing is that if chemically reducing conditions exist in the repository, the actinides are not readily moved in the groundwater pathways; they are quite insoluble under such conditions. However, for some invasive scenarios, e.g., human intrusion actinide release may occur and cause some risk. Otherwise, the principal doses to humans after long periods of time are due mainly to fission products ^{99}Tc and ^{129}I that are water soluble and so are moved through groundwater pathways.

An analysis recently completed by the National Academy of Sciences (NAS) studied the environmental effects of transmutation of all the actinides and found that there was no reason to abandon the once-through fuel cycle.[16] There could be some small reduction in the amount of long-term risk to the public if the two fission product species above were transmuted along with neptunium. The plutonium species appearing in the NAS study combine for less than 0.1% of the risk from these two fission products, and only under the circumstances that the plutonium is extremely mobile.

To the extent that plutonium would replace uranium as reactor fuel, the amount of uranium that needs to be mined, and therefore short-term radiation exposures from mining and milling, will be reduced. However, there will be a short-term increase in radiation exposure from reprocessing and other fuel-cycle activities not part of the once-through fuel cycle. The population doses from these sources are small compared to natural background doses.

The solubility of neptunium is very sensitive to chemical environment, resulting in some uncertainty as to the risk from this species in the once-through fuel cycle. When all error limits are put to their highest values for solubility, the resulting doses from ^{237}Np can be higher than from ^{99}Tc and ^{129}I . The peak doses from ^{237}Np would tend to occur at about a million years in the future. If the effective solubility of neptunium does turn out to be near the high end of the range of possible values, reprocessing of spent fuel, could be beneficial to repository performance if neptunium is recycled along with the plutonium.

If the radioisotopes of concern were separated from the spent fuel process stream and packaged into specialized waste forms, reductions in long-term doses to the public may occur. This would involve separating the Neptunium, Tc and Iodine by chemical means and forming them into insoluble compounds. These compounds would be specially packaged in glass, ceramic or other material. This technology is well within reach, and the idea has been around since at least 1983, but reprocessing of spent fuel for this purpose alone would be extremely expensive.[17]

Estimates of long-term effects from any of these actions are very small in an absolute sense. The National Council on Radiation Protection and Measurements estimates 0.3 latent cancer facilities per Gwe-yr from the whole once-through fuel cycle. The elimination of long-term risk by reprocessing fuel and taking all these steps would amount to 0.06, according to the National Academy of Sciences. Such a savings is very small.

The EPRI study claimed that a factor of two higher packing density of waste in a repository is possible when the plutonium is removed, because of reduced heat output and an assumed fixed heat loading density in the repository. This could be true if the heat loading density in a geological repository is fixed at a given density, as it is now. However, because at least two studies have determined that higher heat loads may be beneficial to repository performance, the loading density limit is currently under investigation.[18,19]

To understand this, one must first understand that the primary (although not only) radionuclide release mechanisms require that groundwater contact the waste packages, degrade the package to expose radionuclides, dissolve the waste form and transport the radionuclides into the biosphere. The proposed location for the national repository is several hundred feet above the water table, so that the only water that shall make contact with the waste is percolating rainwater. The advantage of having heat generation within the packages is that it will prevent them from contacting water because they would be above the boiling point of water for thousands of years. Although design details are not complete at this time, it appears that it may be possible to maintain a dry environment at the surface of the waste containers for many thousands of years.

VII. Conclusions

Many changes have taken place in the world in the past twenty years but the conclusion about reprocessing US spent commercial fuel remain the same. The role of nuclear power in the US has declined from all of the projections that were being made at that time. The market price of uranium has dropped precipitously and many new reserves have been found. Nuclear proliferation projections have mostly not materialized, fortunately, but the threat of diversion of materials where reprocessing is used remains very real. A number of nations have considered developing nuclear weapons and then backed away.

The distress caused by delays in the nuclear waste program were inevitable because the original acceptance date for spent nuclear waste in the 1982 NWPA was not implementable. Characterization studies should continue at Yucca Mountain, NV for disposal of spent fuel in the nation's first high-level waste repository. Although the timetable has slipped, adequate progress is being made.

The US Civilian Nuclear Waste program should not be made a scapegoat for lack of public acceptance of nuclear power. The public acceptance problems of the industry are of a much greater extent than the public doubts about nuclear waste disposal progress. There should be little objection to further expansion of the reactor spent-fuel storage capacity at reactor sites. Dry storage of spent nuclear fuel has been licensed by the Nuclear Regulatory Commission at many sites and has been implemented usually without excessive difficulty. Hardship cases among the nuclear utilities should be handled by the DOE on a case-by-case basis.

It is to be remembered that our policy against reprocessing does not damage the nuclear power industry. In fact, the introduction of a new and very costly fuel cycle which provides no significant environmental or waste disposal benefits could only do the industry great damage. While there is no immediate prospect for investment in nuclear power plants, things could change. If nuclear energy is to be a viable option for the future in the US, it will be with uranium fuel only. The time is coming when the nation will need many new power plants to meet growing needs for electricity and to replace obsolete plants. And when that time does come, it is hoped that issues involving nuclear energy can be debated openly and honestly, not just emotionally as has often been the case.

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[1] A. D. Rossin, "U. S. Policy On Spent Fuel Reprocessing: The Issues" can be viewed at http://www-leland.stanford.edu/group/CISAC/test/pub/rossinpbs.html

[2] J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," Science and Global Security, Vol. 4, 1993, page 111-128.

[3] W. E. Epstein, "The Proliferation of Nuclear Weapons," Scientific American 232, (1975) pp. 18-33.

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